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(54) **CATALYST ASSEMBLY FOR TREATING
ENGINE EXHAUST**

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502/527.19

See application file for complete search history.

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Kushman P.C.

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B01D 2255/9032 (2013.01); **B01D 2279/30**
(2013.01); **B01J 23/72** (2013.01); **B01J 23/745**
(2013.01); **B01J 35/04** (2013.01); **Y02T 10/24**
(2013.01)

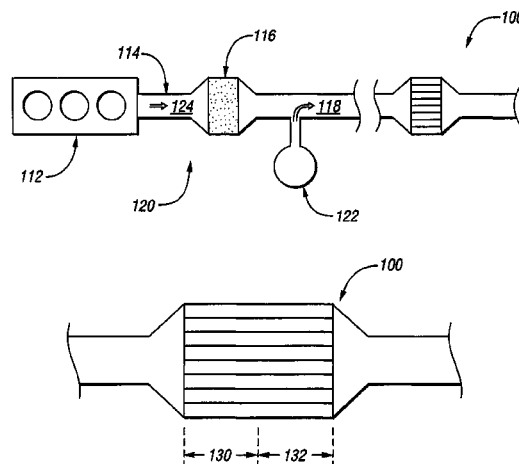
(58) **Field of Classification Search**

USPC 502/240, 244, 245, 258, 300, 327, 331,

(57) **ABSTRACT**

According to one aspect of the present invention, a catalyst
assembly is provided for treating an exhaust from an engine.
In one embodiment, the catalyst assembly includes a first
catalyst material catalytically active at a first temperature and
loaded at a first catalyst material loading, the first catalyst
material including a first base metal loading, and a second
catalyst material catalytically active at a second temperature
lower than the first temperature and loaded at a second cata-
lyst material loading, the second catalyst material including a
second base metal loading, wherein the second base metal
loading is higher than the first base metal loading.

16 Claims, 8 Drawing Sheets



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B01J 23/74 (2006.01)
B01J 20/00 (2006.01)
B01D 53/94 (2006.01)
B01J 23/745 (2006.01)
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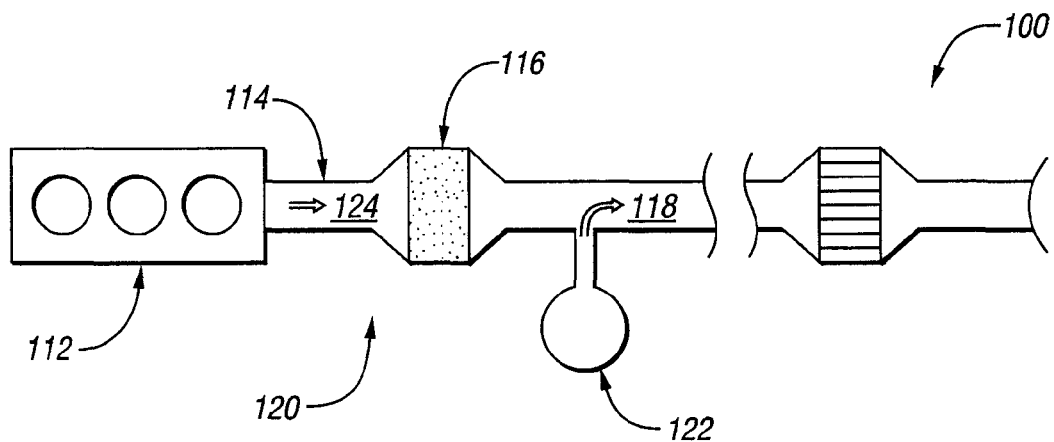


Fig. 1a

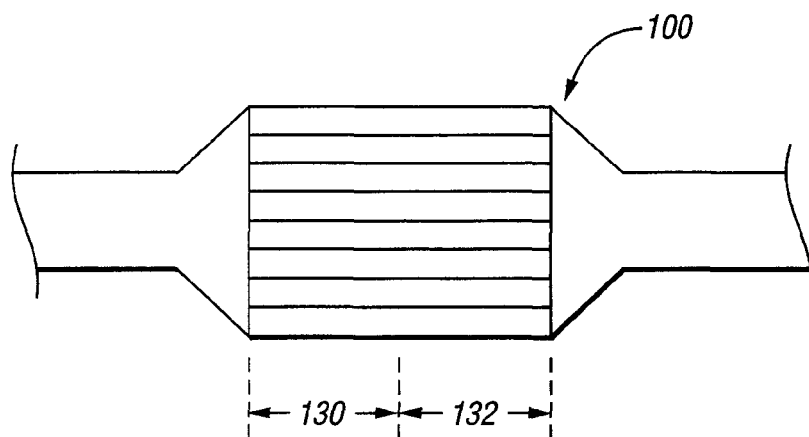


Fig. 1b

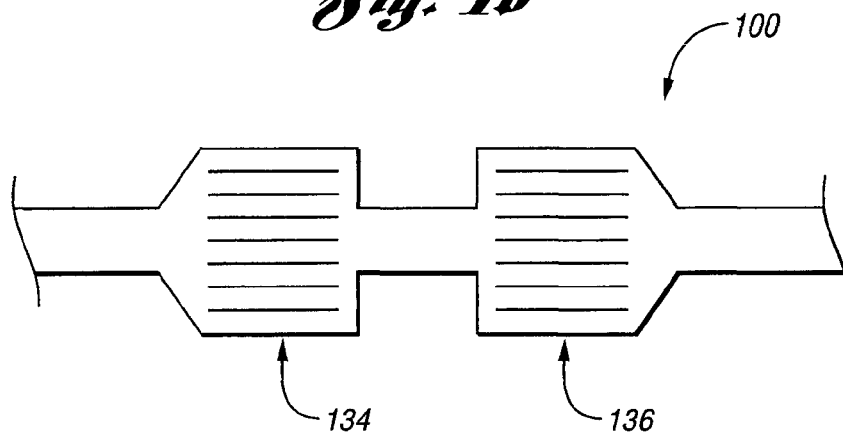


Fig. 1c

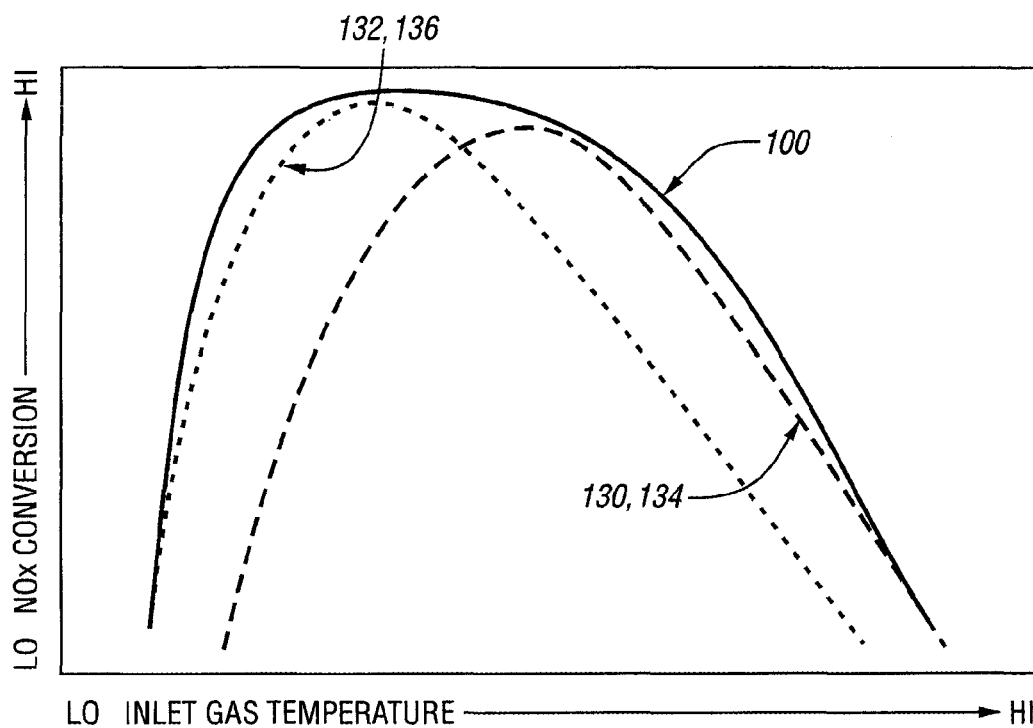


Fig. 1b

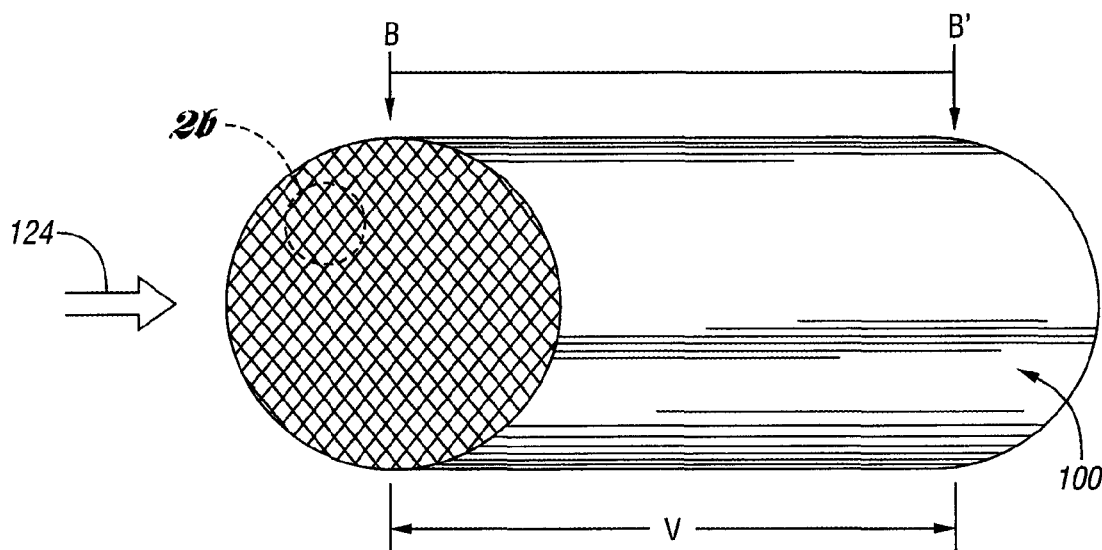


Fig. 2a

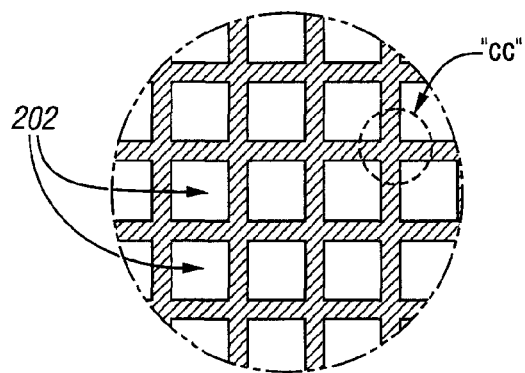


Fig. 2b

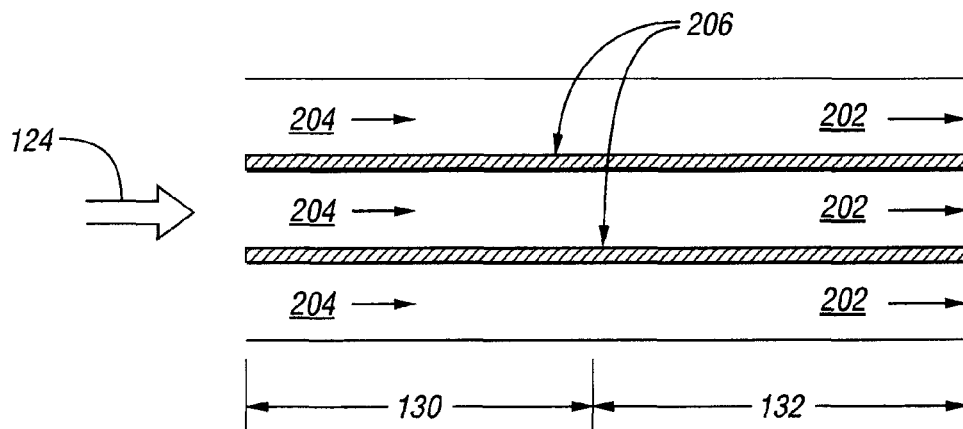


Fig. 2c

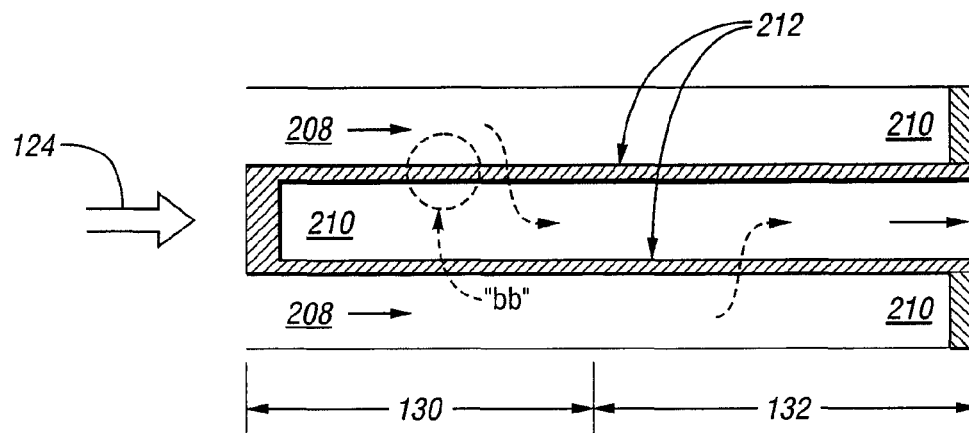


Fig. 2d

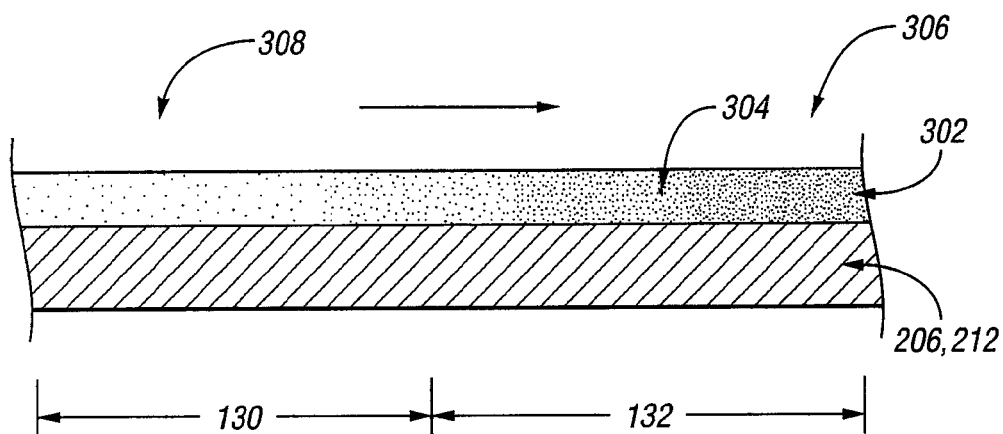


Fig. 3a

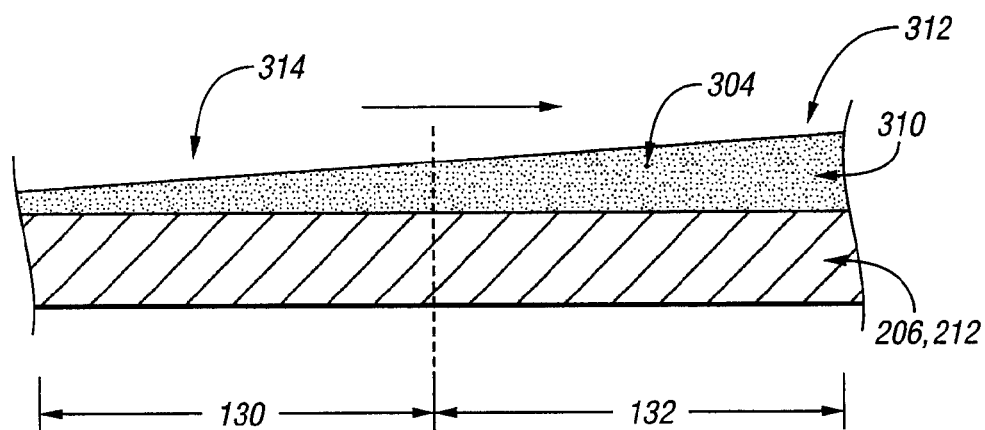


Fig. 3b

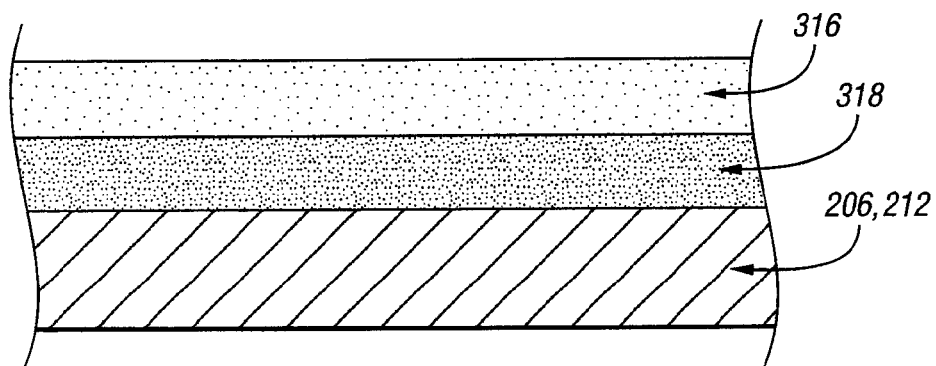


Fig. 3c

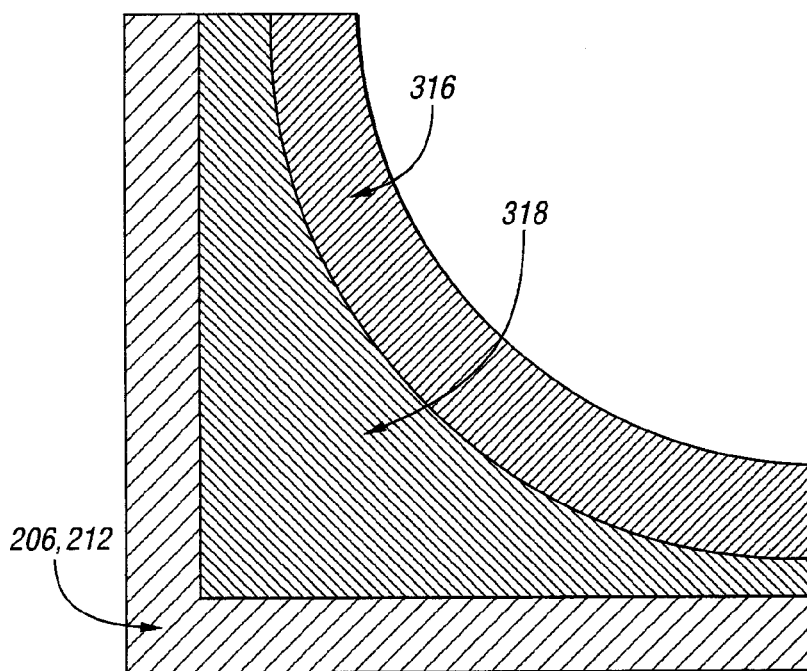


Fig. 3d

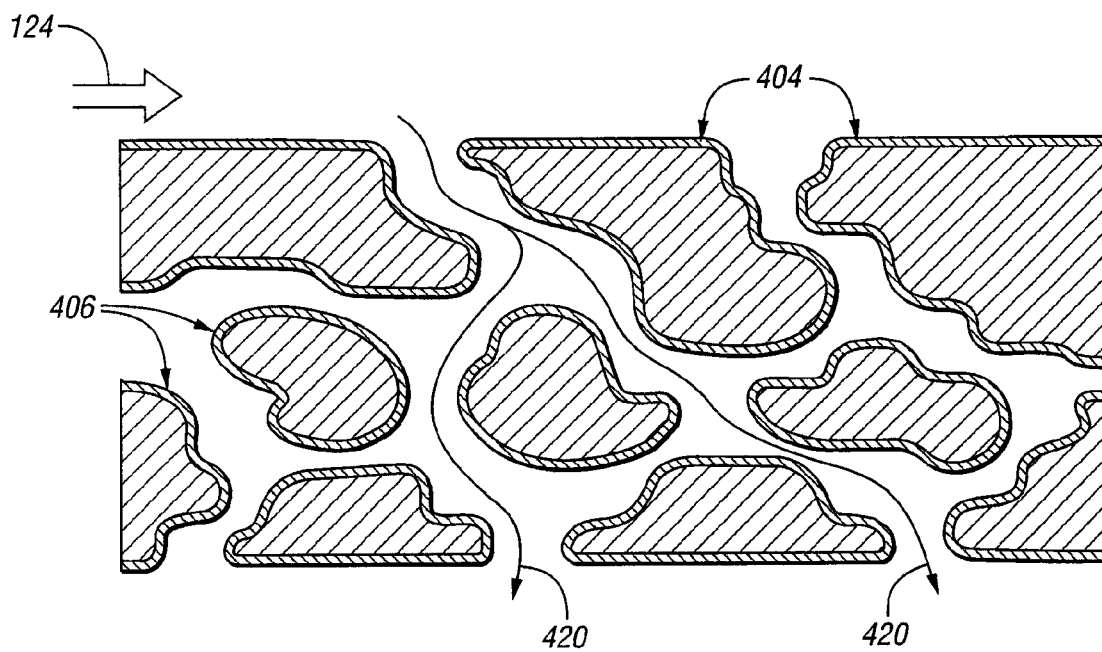
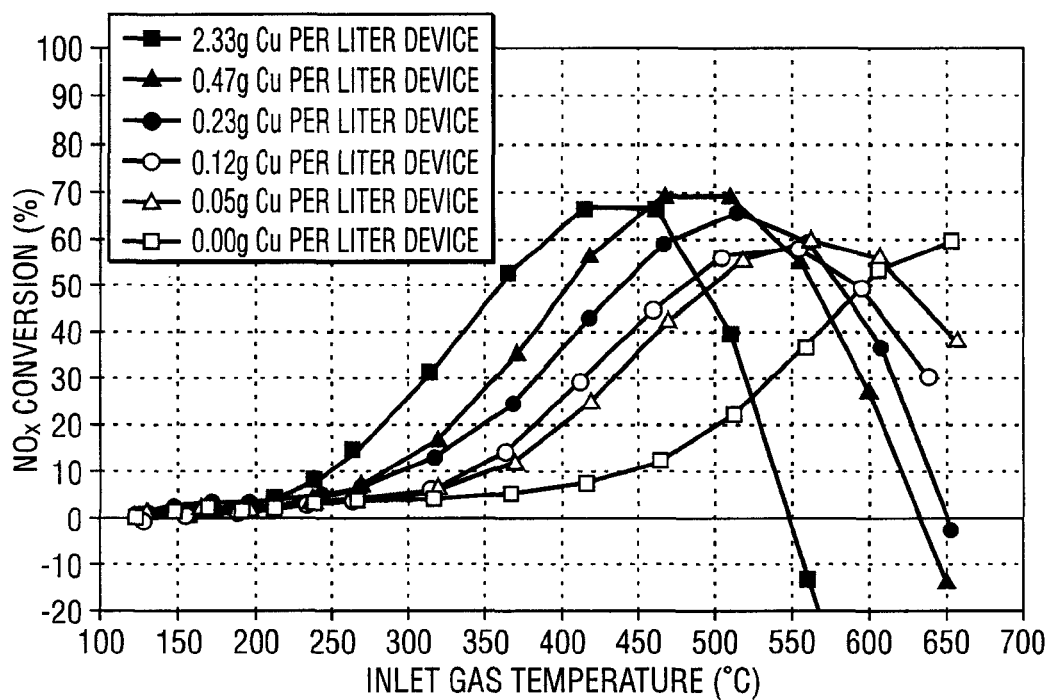
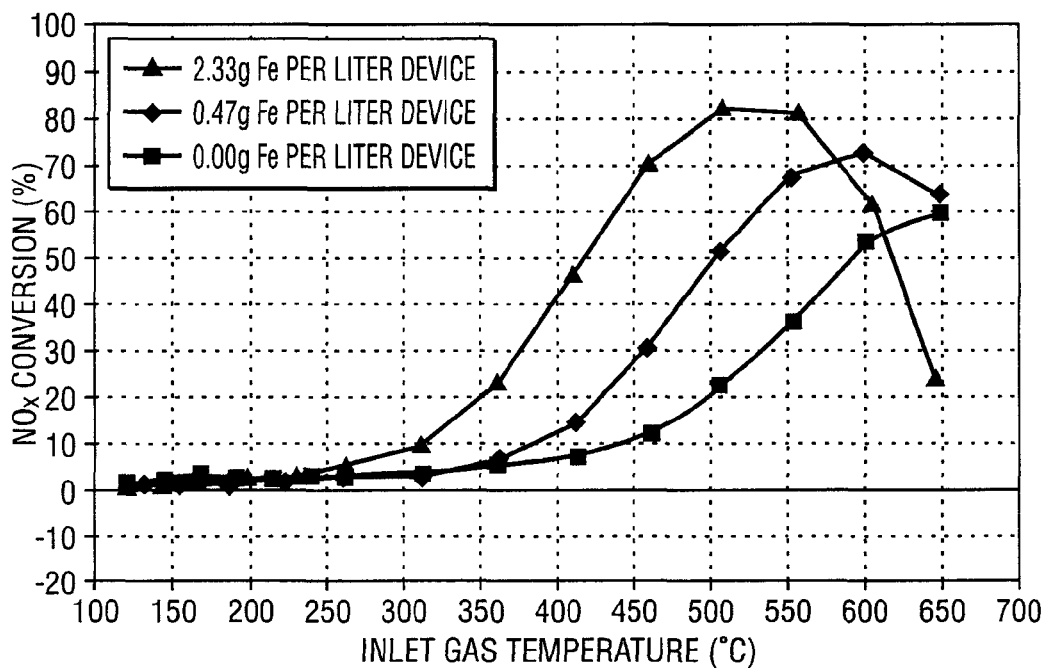
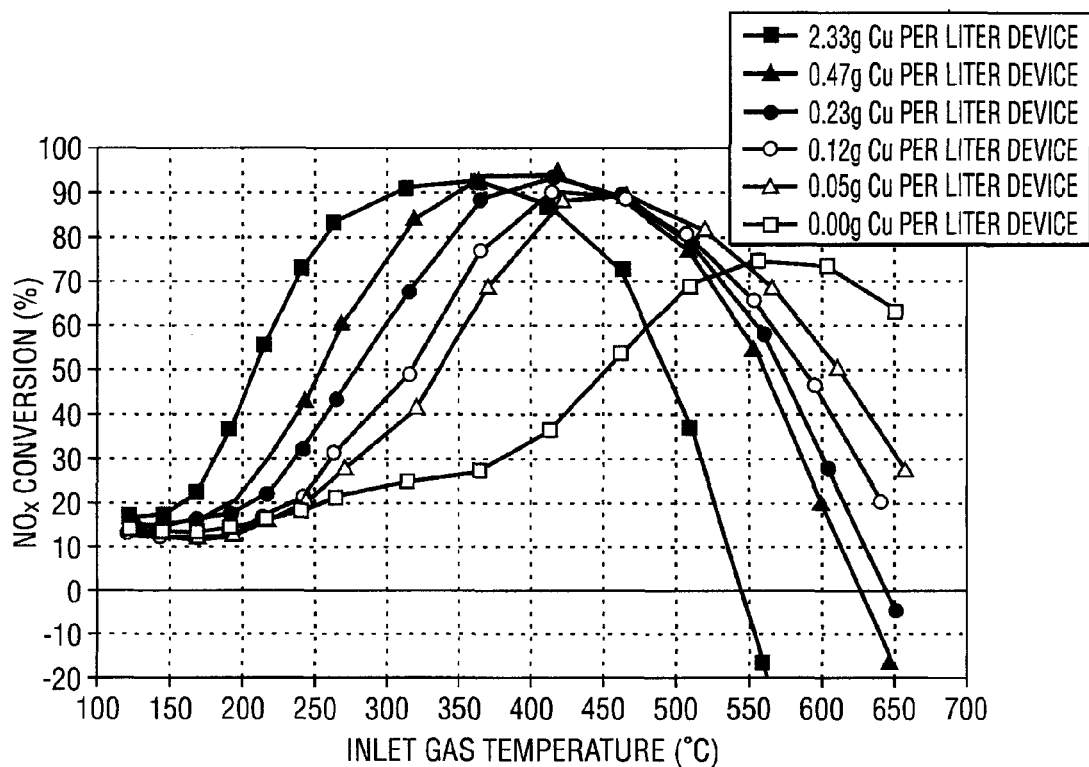
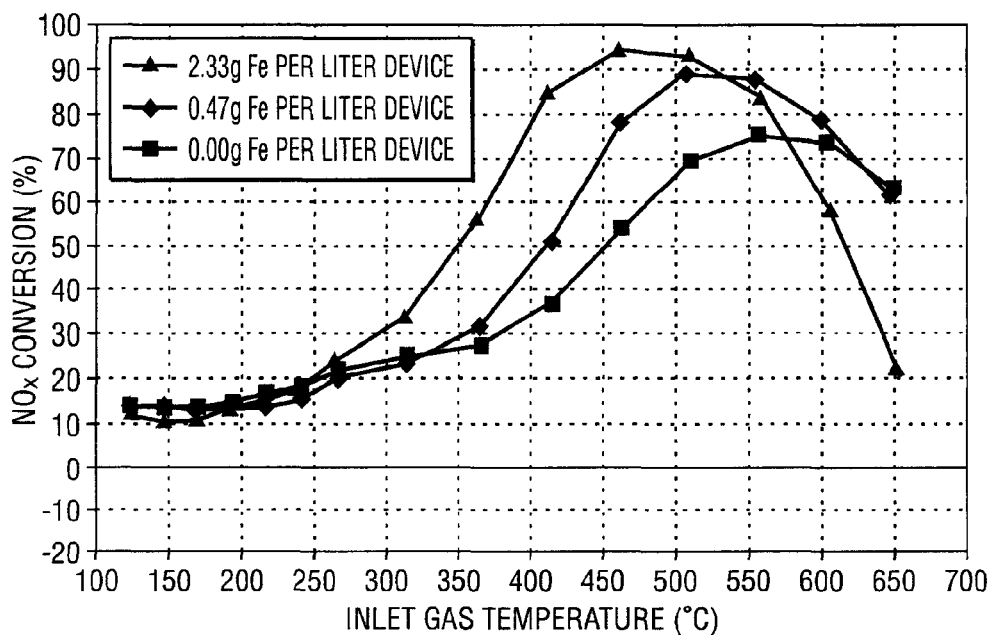
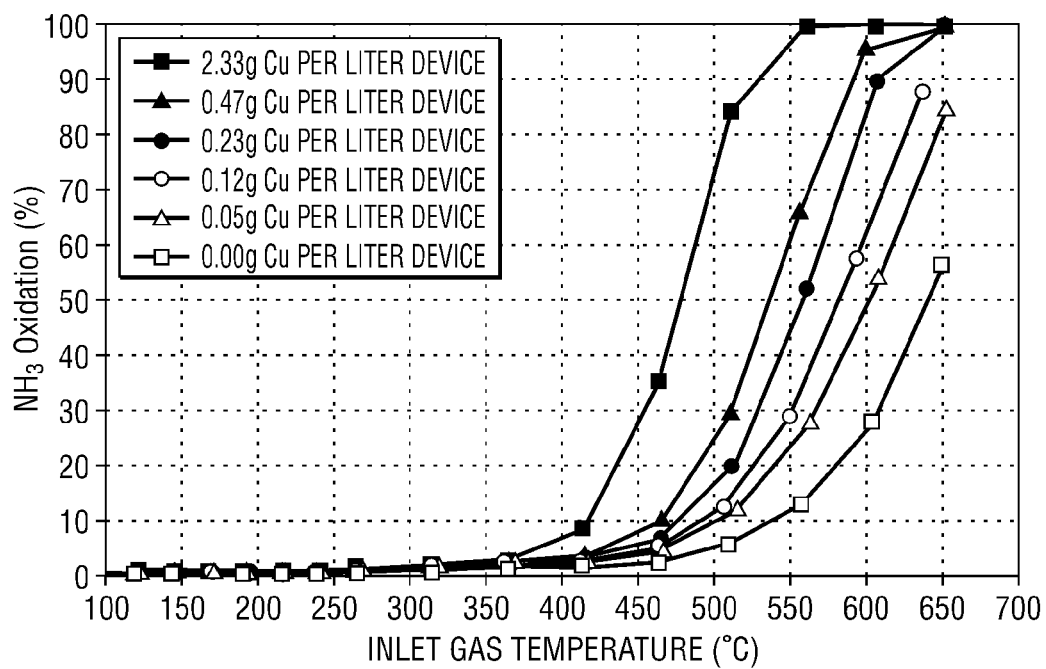
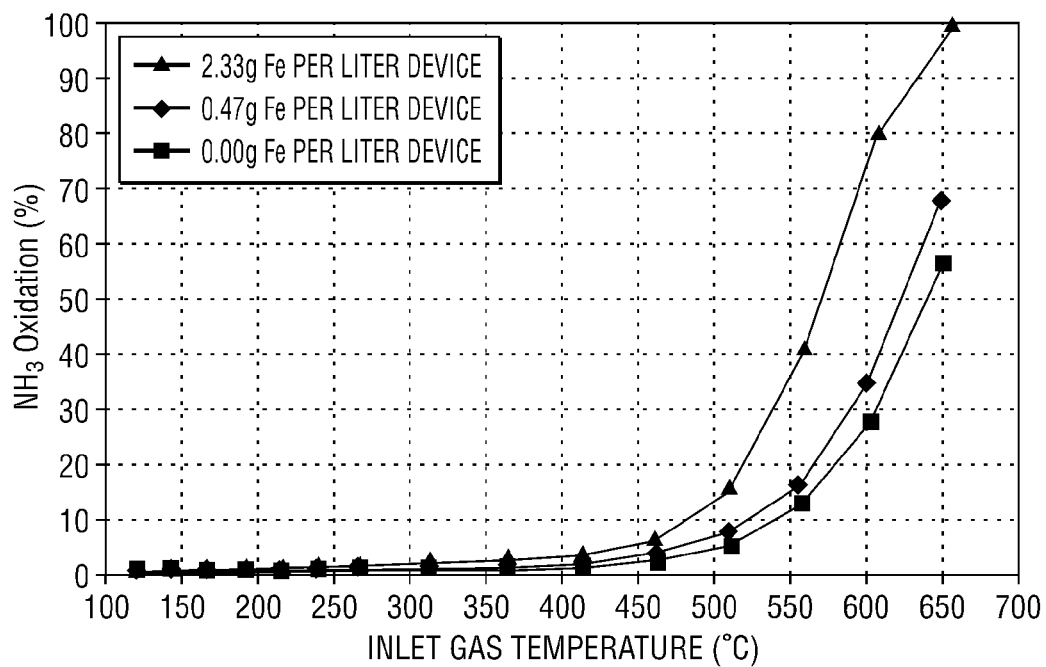


Fig. 4

*Fig. 5a**Fig. 5b*

*Fig. 6a**Fig. 6b*

*Fig. 7a**Fig. 7b*

1

CATALYST ASSEMBLY FOR TREATING ENGINE EXHAUST

BACKGROUND

1. Technical Field

One or more embodiments of the present invention relate to a catalyst assembly for treating engine exhaust.

2. Background Art

Like gasoline engines, diesel engines have been widely used for transportation and stationary applications. A combustion exhaust from diesel engines often contains a variety of combustion waste materials including unburned hydrocarbon (HC), carbon monoxide (CO), particulate matter (PM), nitric oxide (NO), and nitrogen dioxide (NO₂), with NO and NO₂ collectively referred to as nitrogen oxide or NO_x. Removal of CO, HC, PM, and NO_x from the combustion exhaust is needed for cleaner emissions. The combustion exhaust treatment becomes increasingly important in meeting certain emission requirements.

Conventional emission control systems often use selective catalytic reduction (SCR) catalyst for the reduction of NO_x. Urea SCR technology using base metal containing catalysts, in particular, is under development to reduce NO_x emission from lean gasoline and diesel engine exhaust gas. Efficient NO_x reduction is needed in a relatively broad temperature range, for instance at low temperatures during cold start events and at high temperatures during diesel particulate filter (DPF) events and lean gasoline highway conditions.

SUMMARY

According to one aspect of the present invention, a catalyst assembly is provided for treating an exhaust from an engine. In one embodiment, the catalyst assembly includes a first catalyst material catalytically active at a first temperature and loaded at a first catalyst material loading, the first catalyst material including a first base metal loading; and a second catalyst material catalytically active at a second temperature lower than the first temperature and loaded at a second catalyst material loading, the second catalyst material including a second base metal loading, wherein the second base metal loading is higher than the first base metal loading.

In another embodiment, the first and second catalyst materials are positioned to be in contact with the exhaust at a relatively higher temperature and a relatively lower temperature respectively. In certain instances, the first catalyst material is positioned between the engine and the second catalyst material. In certain other instances, the catalyst assembly further includes a substrate for supporting the first and second catalyst materials, wherein the second catalyst material is disposed between the substrate and the second catalyst material.

In yet another embodiment, the first and second base metals each include copper, and wherein the loading of copper in the first catalyst material is lower than the loading of copper in the second catalyst material. In certain instances, the loading of copper in the first catalyst material is from 0 g/l to 3.5 g/l and the loading of copper in the second catalyst material is from 1.5 g/l to 9.5 g/l.

In yet another embodiment, the first and second base metals each include iron, and wherein the loading of iron in the first catalyst material is lower than the loading of iron in the second catalyst material. In certain instances, the loading of iron in the first catalyst material is from 0 g/l to 3.5 g/l and the loading of iron in the second catalyst material is from 1.5 g/l to 9.5 g/l.

2

In yet another embodiment, the first catalyst material loading is different from the second catalyst material loading based on dry weight. In certain instances, the first catalyst material loading is lower than the second catalyst material loading based on dry weight.

In yet another embodiment, the first and second catalyst materials are supported on a honeycomb monolith substrate. In yet another embodiment, the honeycomb monolith substrate is selected from the group consisting of a flow-through honeycomb monolith substrate, a wall-flow honeycomb monolith substrate, and combinations thereof.

According to another aspect of the present invention, a method is provided for reducing gases from the exhaust of an internal combustion engine. In one embodiment, the method includes contacting the exhaust with a catalyst as described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1a depicts an emission control system containing a catalyst according to one aspect of the present invention, for reducing waste materials from the exhaust of an internal combustion engine;

FIG. 1b depicts a schematic view of catalyst of FIG. 1a configured as a single brick having a first and a second portions;

FIG. 1c depicts a schematic view of catalyst configured as two spaced apart bricks;

FIG. 1d depicts a schematic view of a broadened temperature window for NO_x conversion realized by the catalyst of FIG. 1a;

FIG. 2a depicts a schematic view of the catalyst of FIG. 1B having honeycomb type of flow channels;

FIG. 2b depicts an enlarged cross section of the catalyst of FIG. 2a;

FIG. 2c depicts a vertical cross-section along line BB' of the catalyst of FIG. 2a, wherein the honeycomb flow channels are configured for flow-through operation;

FIG. 2d depicts a vertical cross section along line BB' of the catalyst of FIG. 2a, wherein the honeycomb flow channels are configured for wall-flow operation;

FIG. 3a depicts an enlarged view of a portion of the substrate walls in relation to FIGS. 2c and 2d;

FIG. 3b depicts an another enlarged view of a portion of the substrate walls in relation to FIGS. 2c and 2d;

FIG. 3c depicts a yet another enlarged view of a portion of the substrate walls in relation to FIGS. 2c and 2d;

FIG. 3d depicts an enlarged view of the area "cc" of FIG. 2b;

FIG. 4 depicts an enlarged view of a portion of the substrate walls showing internal pores in relation to FIG. 2d;

FIG. 5a depicts a plot of NO_x conversion for a copper-containing SCR core sample, as a function of inlet gas temperature when only NO is introduced into the inlet gas, as referenced in the Example section;

FIG. 5b depicts a plot of NO_x conversion for an iron-containing SCR core sample, as a function of inlet gas temperature when only NO is introduced into the inlet gas, as referenced in the Example section;

FIG. 6a depicts a plot of NO_x conversion for a copper-containing SCR core sample, as a function of inlet gas temperature when 50/50 NO/NO₂ is introduced into the inlet gas, as referenced in the Example section;

FIG. 6b depicts a result graph of NO_x conversion for an iron-containing SCR core sample, as a function of inlet gas temperature when 50/50 NO/NO₂ is introduced into the inlet gas, as referenced in the Example section;

3

FIG. 7a depicts a plot of NH_3 oxidation for a copper-containing SCR core sample, as a function of inlet gas temperature when the inlet gas contains NH_3 and does not contain NO or NO_2 , as referenced in the Example section; and

FIG. 7b depicts a plot of NH_3 oxidation for an iron-containing SCR core sample, as a function of inlet gas temperature when the inlet gas contains NH_3 and does not contain NO or NO_2 , as referenced in the Example section.

DETAILED DESCRIPTION

As required, detailed embodiments of the present invention are disclosed herein. However, it is to be understood that the disclosed embodiments are merely exemplary of the invention that may be embodied in various and alternative forms. The figures are not necessarily to scale; some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for the claims and/or a representative basis for teaching one skilled in the art to variously employ the present invention.

Moreover, except where otherwise expressly indicated, all numerical quantities in the description and in the claims are to be understood as modified by the word “about” in describing the broader scope of this invention. Also, unless expressly stated to the contrary, the description of a group or class of material as suitable or preferred for a given purpose in connection with the invention implies that mixtures of any two or more members of the group or class may be equally suitable or preferred.

With respect to the Figures that will be described in detail below, like numerals are used to designate like structures throughout the Figures.

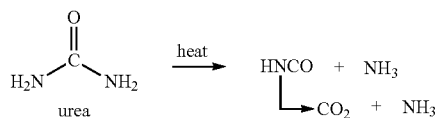
In one or more embodiments, “SCR” means selective catalytic reduction and includes a reducing catalyst which speeds or enhances a chemical reduction of NO_x through the assistance of a reductant. In certain particular instances, the selective catalytic reduction catalyst is supported on a flow-through honeycomb monolith substrate and/or a wall-flow honeycomb monolith substrate.

In one or more embodiments, “ NO_x ” means nitrogen oxide and illustratively includes a mixture of compounds of nitric oxide (NO) and nitrogen dioxide (NO_2).

In one or more embodiments, “DPF” or “DF” refers to the particulate filter employed to remove particulate matter or the like. In certain particular instances, the particulate filter is based on a wall-flow honeycomb monolith substrate.

In one or more embodiments, emission control systems typically use selective catalytic reduction (SCR) catalysts to convert certain waste materials including NO_x to form less harmful counterparts such as N_2 , for safer emissions. Ammonia is a commonly used reductant for SCR catalyst catalyzed NO_x conversion. Decomposition of urea and subsequent reduction of NO_x typically occurs according to the following scheme:

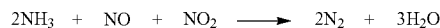
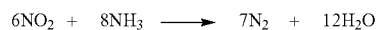
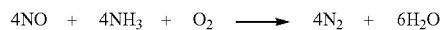
Urea decomposition:



4

-continued

NO_x reduction:



According to one aspect of the present invention, an emission control system is provided for reducing waste species from the exhaust of an internal combustion engine. The waste species from the exhaust of an internal combustion engine may include unburned hydrocarbon (HC), carbon monoxide (CO), particulate matters (PM), nitric oxide (NO), and nitrogen dioxide (NO_2), with NO and NO_2 , collectively referred to as nitrogen oxide or NO_x .

In one or more embodiments, and as depicted in FIG. 1a, an emission control system, generally shown at 120, includes an exhaust passage 114 for transporting the exhaust 124 from the engine 112, a reductant 118 disposed within the exhaust passage 114 downstream of the engine 112, and a catalyst assembly 100 which is to be described in more details herein below. The reductant 118 includes ammonia, liquid urea, solid urea, or combinations thereof and can be optionally supplied from a container 122. In at least another embodiment, an oxidation catalyst 116 is disposed in the passage 114 upstream of the catalyst assembly 100 to catalyze certain reactions such as reactions for converting NO to NO_2 .

It has been found, according to one or more embodiments of the present invention, for a given NO_x conversion rate, a catalyst composition containing a relatively higher base metal loading can achieve the given NO_x conversion at a relatively lower operating temperature. Therefore, the catalyst can be strategically provided with a first portion configured for operation at a relatively higher temperature and a second portion configured for operation at a relatively lower temperature, wherein a first base metal loading in the first portion can be relatively reduced, and any portion or the whole of the reduced amount from the first portion can be added back to the second portion to enhance the relatively low temperature operation. As a result of this base metal segmentation and orientation, an overall temperature window can be broadened while the total amount of base metal required for carrying out the given NO_x conversion is no greater than the amount otherwise needed without segmentation or orientation.

According to one aspect of the present invention, a catalyst assembly is provided for treating an exhaust from an engine. In one or more embodiments, and as depicted in FIGS. 1a-1c, the catalyst assembly generally shown at 100 includes a first catalytic portion 130 or 134 having a first catalyst material (not shown) catalytically active at a first temperature, the first catalyst material having a first base metal loading and a first catalyst material loading; and a second catalytic portion 132 or 136 having a second catalyst material (not shown) catalytically active at a second temperature lower than the first temperature, the second catalyst material having a second base metal loading and a second catalyst material loading, wherein the second base metal loading is higher than the first base metal loading.

As used herein according to one or more embodiments, the first or the second catalyst material is “catalytically active” in a given temperature when at that temperature, the first or the second catalyst material is able to convert 85 percent or more by volume of NO_x to nitrogen.

In yet another embodiment, and as depicted in FIG. 1a, the first and second catalyst materials are positioned to be in

contact with the exhaust **124** at a relatively higher temperature and a relatively lower temperature respectively.

As indicated, the catalyst assembly **100** can be provided with a relatively broadened temperature window for NO_x conversion as compared to conventional catalyst compositions which are merely directed to operation at either relatively low temperatures, for instance at from 150° C. to 500° C. (degrees Celsius) or relatively high temperatures, for instance at from 450° C. to 750° C. As depicted in FIG. **1d**, the catalyst assembly **100** can be formed of two or more formulations strategically arranged such that NO_x conversion can be effectively carried out at temperatures where either formation alone does not deliver the same NO_x conversion at a total given amount of base metal content.

For instance, and as depicted in FIG. **1b**, the catalyst assembly **100** can be arranged as a single brick having a first portion **130** configured for operation at relatively high temperatures 450° C. to 750° C. and a second portion **132** configured for operation at relatively low temperatures 150° C. to 500° C. Alternatively, and as depicted in FIG. **1c**, the catalyst assembly **100** may be arranged as two spaced apart bricks **134**, **136**, functionally equivalent to the first and second portions **130**, **132** in relation to FIG. **1b**. The catalyst assembly **100** can be modified, for instance, to include more than two portions or two bricks, as long as the catalyst assembly **100** as modified is still able to provide a broadened operating temperature window as described herein. For the purpose of illustration, the following description is directed to the catalyst assembly **100** arranged as a single catalyst brick as depicted in FIG. **1b**. However, the same description is similarly applicable to alternative arrangements of the catalyst assembly **100** as indicated herein elsewhere.

In one or more embodiments, and as depicted in FIG. **2a**, the catalyst assembly **100** is arranged as a single brick having a plurality of honeycomb type flow channels **202** extending in a direction substantially parallel to the exhaust flow **124**. FIG. **2b** depicts an enlarged view of the cross-section of FIG. **2a**. Area "cc" as depicted in FIG. **2b** will be detailed in relation to FIG. **3d**.

A vertical cross-section taken along line BB' of the catalytic assembly **100**, as depicted in FIG. **2c**, illustratively shows open ends **204** of the flow-through channels **202** defined by the substrate walls **206**. In this arrangement, a substantially amount of the exhaust **124** pass through the channels **202** and very little amount of the exhaust **124** passes through the substrate walls **206**. This design of the substrate walls is useful where the catalyst assembly **100** functions as a flow-through SCR catalyst.

Alternatively, and as depicted in FIG. **2d**, the catalyst assembly **100** is configured as a wall-flow particulate filter supporting thereupon SCR catalyst materials. A vertical cross-section taken along line BB' of the catalytic assembly **100** illustratively shows open ends **208** and close ends **210** of the channels **202** defined by the substrate walls **212**. In this arrangement, the exhaust **124** enters the channels **202** via open ends **208** and passes through the substrate walls **212**. This design of the substrate walls is useful where the catalyst assembly **100** functions as a wall-flow particulate matter filter supporting SCR catalyst materials.

FIG. **4** depicts an enlarged view of a portion "bb" of the substrate walls **212** in relation to FIG. **2d**, showing internal pores due to the relatively high porosity of the substrate walls **212**, exemplifying a particular filter arrangement. Due to the presence of internal pores collectively shown as unshaded paths **420**, the first and second catalyst materials can be applied to the wall surfaces **404** and/or the pore surfaces **406** in similar coating configuration discussed in relation to FIGS.

3a-3c. In particular, both the wall surfaces **404** and the pore surfaces **406** can be in contact with the catalyst layer **302** according to FIG. **3a**, with the catalyst layer **310** according to FIG. **3b**, with the catalyst layers **316** and **318** according to FIG. **3d**.

In one or more embodiments, the differential base metal loading between the first and second portions **130**, **132** of FIG. **1b** can be arranged according to FIG. **3a** wherein the substrate walls **206** of FIG. **2b** and/or the substrate walls **212** of FIG. **2c** can be in contact with a catalyst layer **302**. As depicted in FIG. **3a**, the catalyst layer **302** collectively represent in a continuous manner the first and second catalyst materials **308**, **306** of the first and second portions **130**, **132** respectively, with a generally heavier content of base metals **304** in the second portion **132** relative to the first portion **130**. In certain particular instances, the catalyst coating **302** has substantially uniform coating thickness with an increasing content of the base metals **304** in the direction of an exhaust flow with arrow shown.

In one or more embodiments, the differential base metal loading between the first and second portions **130**, **132** of FIG. **1b** can be arranged according to FIG. **3b** wherein the substrate walls **206** of FIG. **2b** and/or the substrate walls **212** of FIG. **2c** can be in contact with a catalyst layer **302**. As depicted in FIG. **3b**, the catalyst layer **302** collectively represent in a continuous manner the first and second catalyst materials **314**, **312** of the first and second portions **130**, **132** respectively, with a generally thicker loading of the second catalyst material in the second portion **132** relative to the first portion **130**. In certain particular instances, the catalyst coating **302** is provided with a substantially uniform base metal loading in the direction of an exhaust flow with arrow shown but with an increasing coating thickness along the same direction.

In one or more embodiments, and as depicted in FIG. **3c**, the substrate walls **206** of FIG. **2b**, the substrate walls **212** of FIG. **2c** and/or the internal pores **420** of FIG. **4** can be coated with a intermediate catalyst layer **318** as the first portion configured for operation at relatively lower temperatures and a top catalyst layer **316** as the second portion configured for operation at relatively higher temperatures. Relative to the top catalyst layer **316**, the intermediate catalyst layer **318** can have more base metal loading and/or more catalyst material loading to be configured for operation at a relatively lower temperature.

In one or more embodiments, the substrate walls **206**, **212** defining the flow channels **202** are collectively formed from a material known as a monolith, which is generally described as a ceramic block made of a number of substantially parallel flow channels such as flow channels **202**. The monolith may be made of ceramic materials such as cordierite, mullite, and silicon carbide or metallic materials such as iron chromium alloy, stainless steel, and Inconel®. The channels can be substantially straight, hollow, and parallel to the flow of the exhaust, therefore flow obstruction to the exhaust is minimized. In the event that the substrate is configured as a wall-flow particulate filter for additionally removing the particulate matters, the substrate can further include cordierite, silicon carbide, metal fiber, paper, or combinations thereof.

In yet another embodiment, at least one of the first and second catalyst materials of the catalyst assembly **100** includes zeolite. The term "zeolite" generally refers to a framework aluminosilicate containing atoms of oxygen aluminum and/or silicon. An example of a natural zeolite is mordenite or a chabazite. Synthetic zeolites illustratively include type A as synthetic forms of mordenite, type B as ZSM-5® zeolites, and type Y as ultra-stabilized Beta zeolite.

The framework structure of the zeolites often acquires an overall negative charge compensated for by exchangeable cations which may readily be replaced by other cations such as metal cations through methods including ion exchange. The NO_x occluding catalyst typically includes an alkaline earth metal exchanged zeolite, precious metal exchanged zeolite such as platinum based and/or a base metal exchanged zeolite such as copper and iron based zeolites. While any type zeolite may be used, some suitable zeolites include X type zeolite, Y type zeolite, and/or ZSM-5 type zeolite.

In one or more embodiments, the first and second catalyst materials each independently include at least one base metal selected from the group consisting of copper, nickel, tin, zinc, iron, lead, aluminum, cerium, silver, and combinations thereof.

The first and second base metal loadings can each be defined in terms of grams of the base metal weight per liter of a total loading volume, generally shown at "V" in FIG. 2a.

In yet another embodiment, the first base metal loading as based on the total loading volume "V" of the catalyst assembly 100 is from 0.00 grams per liter (g/l), to 3.50 g/l, 0.00 g/l to 3.00 g/l, or 0.00 g/l to 2.50 g/l. The first base metal loading may be selected based on the substrate material for forming the catalyst assembly 100; however, the first base metal loading as selected is less than the second base metal loading. In certain particular instances, the first base metal loading is from 0.00 g/l to 2.33 g/l when, for instance, the catalyst assembly 100 is formed of cordierite substrate having 300 to 500 CPSI (cells per square inch) and having a wall thickness of 3.0 to 6.0 mil.

In yet another embodiment, the second base metal loading as based on the exterior volume of the catalyst assembly 100 is from 1.50 grams per liter (g/l) to 9.50 g/l, 2.0 g/l to 9.5 g/l, or 2.5 g/l to 9.5 g/l. The second base metal loading may be selected based on the substrate material for forming the catalyst assembly 100; however, the second base metal loading as selected is greater than the first base metal loading. In certain particular instances, the second base metal loading is from 2.33 g/l to 9.33 g/l when, for instance, the catalyst assembly 100 is formed of cordierite substrate having 300 to 500 CPSI and having a wall thickness of 3.0 to 6.0 mil.

The first and second catalyst material loadings can be provided in terms of grams of the catalytic material in dry weight per liter of a loading volume, generally shown at "V" in FIG. 2a. The first and second catalyst material loadings can each be dependent upon various parameters of the substrate, including substrate porosity, length to width aspect ratio, number of flow channels 202, and substrate wall thickness of the flow channels 202.

In yet another embodiment, the first catalyst material loading as based on the loading volume "V" of the catalyst assembly 100 is from 10 grams per liter (g/l) to 300 g/l, 10 g/l to 250 g/l, 10 g/l to 200 g/l, or 10 g/l to 150 g/l. In yet another embodiment, the second catalyst material loading as based on the loading volume "V" of the catalyst assembly 100 is from 50 g/l to 450 g/l, 100 g/l to 450 g/l, 150 g/l to 450 g/l, or 200 g/l to 450 g/l. The first and second catalyst material loadings are calculated based on dry weight of the catalyst materials or the washcoat materials illustratively including one or more of the base metals, one or more types of zeolites, one or more types of binders. In one or more embodiments, the first and the second catalyst material loadings are each referred to as a first and second washcoat loading.

One or more embodiments of the present invention are further illustrated by the following non-limiting examples.

EXAMPLES

Catalyst activity data are obtained using an automated laboratory scale flow reactor system. Custom-written Lab-

VIEW based software with National Instruments data acquisition hardware is used to control MKS mass flow controllers and Lindberg Mini-Mite tubular furnaces. A computer controlled evaluation protocol is run for each same to decrease the test-to-test variations commonly observed by manual operation.

For all the SCR core samples tested in this example, the total gas flow rate is held constant at 6.44 liters/min while the sample size is held constant at 2.54 cm in diameter×2.54 cm in length. As a result, a space velocity equal to 30,000/hr is used in this example. The inlet gas temperature is maintained with one preheat tubular furnace followed by a second tubular furnace. The SCR core samples are loaded in quartz tubing and placed in the second tubular furnace. A Thermo Electron Antaris IGS FTIR Gas Analyzer with a heated sample cell is used at the outlet of the reactor to measure NO, NO₂, N₂O, NH₃, CO₂, and H₂O levels. To cover the full exhaust temperatures expected on diesel vehicles, data are taken at inlet gas temperatures from approximately 150° C. to 700° C. in 25° C.-50° C. steps. The computer-controlled evaluation protocol steps the reaction temperature setting from a high temperature to low temperature for a prescribed duration. At each temperature setting, the duration is chosen so that post SCR gas composition is allowed enough time to equilibrate.

Tables 2-4 show the simulated diesel exhaust gas composition applied to each sample core to study the Standard SCR Reaction, the Fast SCR Reaction, and the Ammonia Oxidation Reaction, respectively. The molar NH₃ to NO_x ratio (ANR) is held constant at 1.0 to represent the stoichiometry of the well known Standard SCR Reaction and Fast SCR Reaction in Equations (1) and (2), respectively. Typical engine-out diesel exhaust contains a higher fraction of NO compared to NO₂. However, exhaust configurations with an upstream oxidation catalyst can be used to oxidize a portion of the NO to NO₂. Finally, the Ammonia Oxidation Reaction is employed to examine NH₃ oxidation by oxygen in the absence of NO_x according to Equation (3).



The standard SCR reaction according to the Equation (1) is employed to determine NO_x conversion efficiency of the SCR core samples when the inlet feed gas contains only NO as the NO_x source as shown in Table 2. The fast SCR reaction according to the Equation (2) is employed to determine NO_x conversion efficiency of the SCR core samples when the inlet feed gas contains both NO and NO₂ as the NO_x source as shown in Table 3. It is well known in the art that a SCR catalyst performs better in NO_x conversion reactions when an exhaust flow is provided with a relatively higher ratio of NO₂ relative to NO as the NO_x source. An increase content of NO₂ can be realized with the use of an oxidation catalyst upstream of the SCR catalyst. This portion of the testing is to further explore the behavior patterns of the catalyst according to certain embodiments of the present invention. The ammonia oxidation reaction according to the Equation (3) is employed to show how well the SCR core samples tolerate the ammonia oxidation insult across a wide range of inlet temperatures.

TABLE 2

Feed gas composition for examining the sample activity under the Standard SCR Reaction	
Feed Gas Composition	Standard SCR Reaction
NO (ppm)	350
NO ₂ (ppm)	0
NH ₃ (ppm)	350
O ₂ (%)	14.0
CO ₂ (%)	5.0
H ₂ O (%)	5.0
N ₂	balance

TABLE 3

Feed gas composition for examining the sample activity under the Fast SCR Reaction	
Feed Gas Composition	Standard SCR Reaction
NO (ppm)	175
NO ₂ (ppm)	175
NH ₃ (ppm)	350
O ₂ (%)	14.0
CO ₂ (%)	5.0
H ₂ O (%)	5.0
N ₂	balance

TABLE 4

Feed gas composition for examining the sample activity under the Ammonia Oxidation Reaction	
Feed Gas Composition	Standard SCR Reaction
NO (ppm)	0
NO ₂ (ppm)	0
NH ₃ (ppm)	350
O ₂ (%)	14.0
CO ₂ (%)	5.0
H ₂ O (%)	5.0
N ₂	balance

FIG. 5a depicts NO_x conversion efficiency, according to Equation (1), as a function of inlet gas temperature among the SCR core samples with various copper loadings, wherein the catalyst core samples have been degreened and the inlet gas contains NO only as the NO_x. As can be seen from FIG. 5a, at an inlet gas temperature up to about 450° C., NO_x conversion efficiency increases with the copper loading for all the samples. For the SCR core samples having a copper content of 0.23 g/l, 0.47 g/l, and 2.33 g/l, corresponding NO_x conversion starts to decrease sharply from between 450° C. to 500° C. For the SCR core samples having relatively lower copper content of 0.12 g/l, and 0.05 g/l, corresponding NO_x conversion peaks at between 500° C. to 550° C. and does not start to fall until after about 550° C.

FIG. 5b depicts NO_x conversion efficiency as a function of inlet gas temperature among the SCR core samples with various iron loadings according to Equation (1), wherein the catalyst core samples have been degreened and the inlet gas contains NO only as the NO_x. As can be seen from FIG. 5b, the iron containing SCR core samples behave similarly to the corresponding copper containing SCR core samples of FIG. 5a;

FIG. 6a depicts NO_x conversion, according to Equation (2), as a function of inlet gas temperature for SCR core samples

with various copper loadings, wherein the SCR core samples have been degreened and the inlet gas contains NO and NO₂ in equal share. As can be seen from FIG. 6a, at an inlet gas temperature up to about 360° C., NO_x conversion efficiency increases with the copper loading for all the core samples. For these SCR core samples having a copper content of 0.23 g/l, 0.47 g/l and 2.33 g/l, corresponding NO_x conversion peaks and then starts to decrease sharply at about 375° C. For the SCR core samples having relatively lower copper content of 0.12 g/l and 0.05 g/l, corresponding NO_x conversion peaks and starts to decrease at about 450° C. Interestingly, for a given NO_x conversion of between about 30 percent to about 85 percent, the inlet gas temperature is reciprocal to the copper loading. For instance, the SCR core sample having 2.33 g/l copper elicits a 60 percent NO_x conversion at an inlet temperature of about 220° C.; the SCR core sample having 0.47 g/l of copper elicits a 60 percent NO_x conversion at an inlet temperature of about 270° C.; the SCR core sample having 0.23 g/l of copper elicits a 60 percent NO_x conversion at an inlet temperature of about 300° C.; the SCR core sample having 0.12 g/l of copper elicits a 60 percent NO_x conversion at an inlet temperature of about 330° C.; and the SCR core sample having 0.05 g/l of copper elicits a 60 percent NO_x conversion at an inlet temperature of about 350° C. In other words, and as can be observed from the results shown herein, for a given NO_x conversion, the higher is the inlet temperature the lower the copper content is needed.

FIG. 6b depicts NO_x conversion efficiency as a function of inlet gas temperature among the SCR core samples with various iron loadings according to Equation (2), wherein the catalyst core samples have been degreened and the inlet gas contains an equal share of NO and NO₂. As can be seen from FIG. 6b, the iron containing SCR core samples behave similarly to the corresponding copper containing SCR core samples of FIG. 6a;

FIG. 7a depicts NH₃ oxidation, according to Equation (3), as a function of inlet gas temperature for SCR core samples with various copper loadings, wherein the SCR core samples have been degreened and the inlet gas contains NH₃ as the only nitrogen source. As well known in the art, NH₃ oxidation is an undesirable side reaction competing for oxygen in an exhaust gas flow. As can be seen from FIG. 7a, all SCR core samples show little or no NH₃ oxidation at an inlet temperature up to 400° C. and elicit a suddenly increased extent of NH₃ oxidation from about 420° C. to about 550° C. Moreover, at an inlet gas temperature from between about 400° C. to about 550° C., NH₃ oxidation is observed to increase with the copper loading. For instance, at the inlet gas temperature of 550° C., NH₃ oxidation for the SCR core sample having 2.33 g/l copper is about 96 percent, for the SCR core sample having 0.47 g/l copper is about 65 percent, for the catalyst core sample having 0.23 g/l copper is about 45 percent, for the SCR core sample having 0.12 g/l of copper is about 33 percent, for the SCR core sample having 0.05 g/l of copper is about 22 percent, and for the SCR core sample having 0.00 g/l of copper is about 10 percent.

While the best mode for carrying out the invention has been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention as defined by the following claims.

What is claimed:

1. An SCR catalyst assembly comprising:

a substrate;

an upstream catalyst material coated onto the substrate, including a first base metal of copper or iron loaded in a first zeolite at an upstream loading of 0 to 3.5 g/l and

11

- having a NO_x conversion activity in a first temperature range of 150° C. to 500° C.; and
- a downstream catalyst material coated onto the substrate downstream of the upstream catalyst material, including a second base metal of copper or iron loaded in a second zeolite at a downstream loading of 1.5 to 9.5 g/l and having a NO_x conversion activity in a second temperature range of 450° C. to 700° C.
2. The assembly of claim 1, wherein the substrate is formed of a plurality of flow channels.
3. The assembly of claim 1, wherein the first and second base metals are copper.
4. The assembly of claim 3, wherein the upstream loading is 0 g/l to 3 g/l.
5. The assembly of claim 3, wherein the downstream loading is 2 g/l to 9.5 g/l.
6. The assembly of claim 1, wherein the first and second base metals are iron.
7. The assembly of claim 6, wherein the upstream loading is 0 g/l to 3 g/l.
8. The assembly of claim 6, wherein the downstream loading is 2 g/l to 9.5 g/l.
9. The assembly of claim 1, wherein the zeolite is an alkaline earth metal exchanged zeolite, a precious metal exchanged zeolite or a base metal exchanged zeolite.
10. The assembly of claim 1, wherein the substrate is formed from a monolith.

12

11. The assembly of claim 10, wherein the monolith is a ceramic material including one or more of cordierite, mullite, and silicon carbide.
12. The assembly of claim 10, wherein the monolith is a metallic material including one or more of an iron chromium alloy, stainless steel, and Inconel.
13. The assembly of claim 10, wherein the upstream and downstream catalyst materials have a substantially uniform coating thickness.
14. The assembly of claim 10, wherein the monolith includes a plurality of flow channels.
15. An SCR catalyst assembly comprising:
an upstream substrate coated with an upstream catalyst material including copper at an upstream loading;
a downstream substrate coated with a downstream catalyst material including copper at a downstream loading; and
the upstream and downstream copper loading is substantially uniform and the upstream and downstream catalyst material have an increasing coating thickness in an exhaust flow direction.
16. The assembly of claim 15, wherein the upstream catalyst material has a NO_x conversion activity at a first temperature and the downstream catalyst material has a NO_x conversion activity at a second temperature less than the first temperature.

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